FINAL REPORT

Analysis of Satellite Data for Sensor Improvement

NASA Grant NGR 14-001-008

01 October 1962 to 30 June 1990

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GENERAL STATEMENT

This grant began shortly after the successful launch of TIROS 1 on April 1, 1960. Fujita was called into NASA to solve their girdding and navigation problems. For two to three years after this grant started, Fujita and his associates solved the gridding method, making use of the celestial coordinates of the spin-axis point.

After the NIMBUS satellite was launched, Fujita and Bandeen collaborated on identifying successive scan lines on the earth, enabling us to locate precisely the scan spots on the earth. Meanwhile, enhancement of radiation data was suggested.

When the gridding accuracy improved, meteorological applications of satellite were explored. The hurricane structure and effects of seeding experiments were studied in cooperation with NHRP (National Hurricane Research Project).

In cooperation with Suomi and Parents of the University of Wisconsin, the "First Color Movie of the Planet Earth" was produced by using a sequence of color pictures of the earth on November 18, 1967 at 30-min intervals.

Since that time, Fujita developed and improved his technique of making movies of all types of nephsystems such as thunderstorms, jetstream cirrus clouds, etc. A list of ten (10) significant movies produced under this grant is shown in p11 and p12.

1974 was the year of the Super-outbreak tornadoes and the year of "Hearings before the Subcommittee on Space Science and Applications." After the hearing, a large-scale investigation of thunderstorm tops during the tornado-bearing stages was undertaken. Among others, it has been confirmed that cloud tops either subside or collapse prior to tornado development.

When the warm wake atop severe thunderstorms were studied extensively by Fujita, resulting in his hypothesis that the wake is caused by the stratospheric cirrus located above the anvil surface. NASA, on the other hand, maintained their view that the emissivity of cloud tops may as well cause the warm wake. This debate could go on for some years to come.

Extensive research on overshooting tops was also performed by photographing the tops from a Learjet flying above the anvil level. Amazingly enough, the time variation of the dome top height is very fast.

After the discovery of downburst by Fujita, a number of attempts were made for detecting downburst clouds prior to their formation. Unfortunately, small downburst cells failed to show specific signatures in satellite pictures.

During the past years, Fujita began thinking about the climatic change of severe storm activities, say, during the 30 to 60 years when rawinsonde data were archived. Fujita's interest consequently widened into climatological researches.

AWARDS RECEIVED

1979: Distinguished Public Service Medal of NASA to Tetsuya T. Fujita for his significant and imaginative utilization of the measurements from low orbiting and geosynchronous meteorological satellites for nearly two decades, resulting in major advances in our understanding the structure and evolution of severe storms.

1985: 25-Years of Weather Satellite Award Medal of the U.S. Department of Commerce to T. Theodore Fujita for creative scientific leadership as an enthusiastic pioneer in the use of satellite imagery to analyze and predict mesoscale weather phenomena and to understand severe thunderstorms, tornadoes, and hurricanes.

PAPERS PUBLISHED UNDER THIS GRANT

Author	Paper Identification Numbers
Arnold, J. E.	5 10
Balogun, E. E.	51
Bandeen, W.	9
Black, P. G.	24 92
Bonner, W. D.	11
Bradbury, D. L.	19
Byers, H. R.	42
Caracena, F.	48 50
Changnon, S. A.	44
Dundus, R.	45
Fletcher, W. L.	2 4
Forbes, G. S.	32 36 40 46 54 75
Fujita, T. T.	1 3 4 5 6 7 8 9 13 16 19 21 23 24 25 26 27 28 30 31 32 33 34 38 39 40 42 43 44 45 47 48 49 50 52 53 56 57 58 59 60 61 62 64 65 66 67 69 70 71 72 76 77 78 80 81 82 84 85 90 91 92 93 94
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Mendez, R.	17
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Wakimoto, R. M.	54 58 60 65 68 71 72 73 74 75 77 78 83 86
Waranauskas, B.R.	79 89
Wilson, J. W.	57

PAPER BY SUBJECT MATTERS

Subjects	Paper Identification Numbers
A. THUNDERSTORM	16 19 28 34 42 51 52 55 56 57 67 68 73 80 79 94
B. HURRICANE	5 15 24 60 82
C. TORNADO	20 23 26 27 30 31 32 36 37 44 46 47 53 54 62 66 71 74 75 85 87 91 94
D. DOWNBURST	40 43 48 50 52 54 59 61 64 65 66 77 80 84 86 89 90 92
E. MESOSCALE FLOW	81 83 88 93
F. CLOUD MOTION	33 39 48
G. PRECISE GRIDDING	1 6 7 10 11 18
H. STEREO	69 70 76
I. EARTH SCANNING	9 10 17 21
J. GROUND TRUTH	12 13 49 58 72
K. STORM TOP	16 25 29 30 35 38 41 51 55 63
L. RAINSTORM	45
M. RADIATION	1 2 3 4 5 6 7 8 14 22

LIST OF PUBLICATIONS

1 Fujita, T., 1963: Outline of a theory and examples for precise analysis of satellite radiation data. MP Res. Paper 15, University of Chicago, 35 pp.

2 Larsen, S.H.H., T. Fujita, and W.L. Fletcher, 1963: Evaluation of limb darkening from TIROS III radiation data. MP Res. Paper 18, University of Chicago, 19 pp.

3 Pedersen, F., and T. Fujita, 1963: Synoptic interpretation of TIROS III measurements of infrared radiation. MP Res. Paper 19, University of Chicago, 39 pp.

4 Larsen, S.H.H., T. Fujita, and W.L. Fletcher, 1963: TIROS III measurements of terrestrial radiation and reflected and scattered solar radiation. MP Res. Paper 20, University of Chicago, 11 pp.

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28 Fujita, T.T., 1973: Thermal and dynamical features of a thunderstorm with a tilted axis of rotation. SMRP Res. Paper 118, University of Chicago, 15 pp.

29 Pearl, E.W., 1974: Characteristics of anvil-top associated with the Poplar Bluff tornado of May 7, 1973. SMRP Res. Paper 119, University of Chicago, 12 pp.

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39 Fujita, T.T., 1976: Spearhead echo and downburst near the approach end of a John F. Kennedy Airport runway, New York City. SMRP Res. Paper 137, University of Chicago, 51 pp.

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50 Fujita, T.T., and F. Caracena, 1977: An analysis of three weather-related aircraft accidents. Bull. Amer. Meteor. Soc., 58, 1164-1181.

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LIST OF SATELLITE MOVIES

When Applications and Technology Satellite (ATS) III was tested in 1967 and 1968, Fujita developed various methods of examining sequences of imagery in the motion picture form. The first attempt was made by using a series of color pictures of the earth taken on November 18, 1967. Both Professors Suomi and Parents contributed significantly to this effort. A list of key movies filmed at the University of Chicago under this grant is presented with a brief explanation of each movie.

A. Color Movie of the Planet Earth (400 ft)

This is the "First Color Movie of the Planet Earth" filmed from the first and only sequence of ATS III color pictures. It was taken every 30 min on November 18, 1967. The film was made by Fujita in cooperation with Professor Verner Suomi at the University of Wisconsin.

B. Tornado Situations on April 19, 1968 (400 ft)

During the Spring season in 1968, NASA conducted the Tornado Watch Experiment. This movie was made by adding red dot at the location of each tornado on the satellite picture at the tornado time. The film was made by Fujita with Suomi and Oliver.

C. Tornado Situations on April 23, 1968 (400 ft)

A large number of tornadoes occurred over a large area from Illinois to Indiana. This movies was made by adding red tornado dots to depict tornado activities in relation to satellite-viewed nephsystems. The film was made by Fujita with Suomi and Oliver.

D. Hurricane Watch Experiment, 1968 (400 ft)

The overall view of Hurricane Abby was filmed for a period of four (4) days from June 3 to 6, 1968. This film was made as a joint effort of Fujita, Suomi, Oliver, and Gentry.

E. Close-up views from Hurricane Watch 1968 (400 ft)

Selected views of small areas inside the hurricane watch imagery in 1968 were used to produce high-resolution movie segments.

JUN 03, 1968	Drifting anvil from Hurricane Abby Sea breeze over the Yucatan Peninsula Arc clouds from thunderstorm areas
JUN 05, 1968	Cloud bands
JUN 22, 1968	Cumulonimbi over Cuba
JUN 23, 1968	Cumulonimbi over Florida

F. Enhanced Imagery of Hurricane Camille, AUG 17, 1969 (200 ft)

The hurricane imagery was enhanced so that the coldest cloud areas are 100% white and the warmer clouds, graduated grey to black. This movie shows excellent 3-dimensional effects. Meanwhile, the identical enhancement was applied to Hurricane Debby, August 20, 1969 imagery to produce Debby's movie. Finally, the coldest areas were enhanced black in order to produce imagery with black cold top.

G. Hurricane Ginger, SEP 25 - 28, 1971 (180 ft)

This hurricane was seeded by NHRL (National Hurricane Research Laboratory) aircraft on alternate days of the experiment: September 25 (no seeding), September 26 (seeded), September 27 (no seeding), and September 28 (seeded). The purpose of the film is to depict the difference in the time-lapse view of a seeded hurricane. Red dots are added on the satellite pictures at the time and location of the seeding aircraft. This was a joint effort of Fujita and Gentry.

H. Overshooting Tops of Thunderstorms May 12, 1972 (180 ft)

Severe thunderstorm clouds were depicted by three scales of motion as viewed at ATS III spin scan camera, and a time-lapse movie camera operated by Fujita on board a research Learjet flying over southern Texas at 47,000 ft pressure altitude. The satellite movie shows the parent thunderstorm and gust fronts radiating out from convective areas.

Detailed motions of the overshooting tops were time-lapsed and re-filmed into 1 sec and 6 sec sequences to show accelerated views of the top of the severe thunderstorm.

I. Tornado Overflight, FEB 23, 1977 (130 ft)

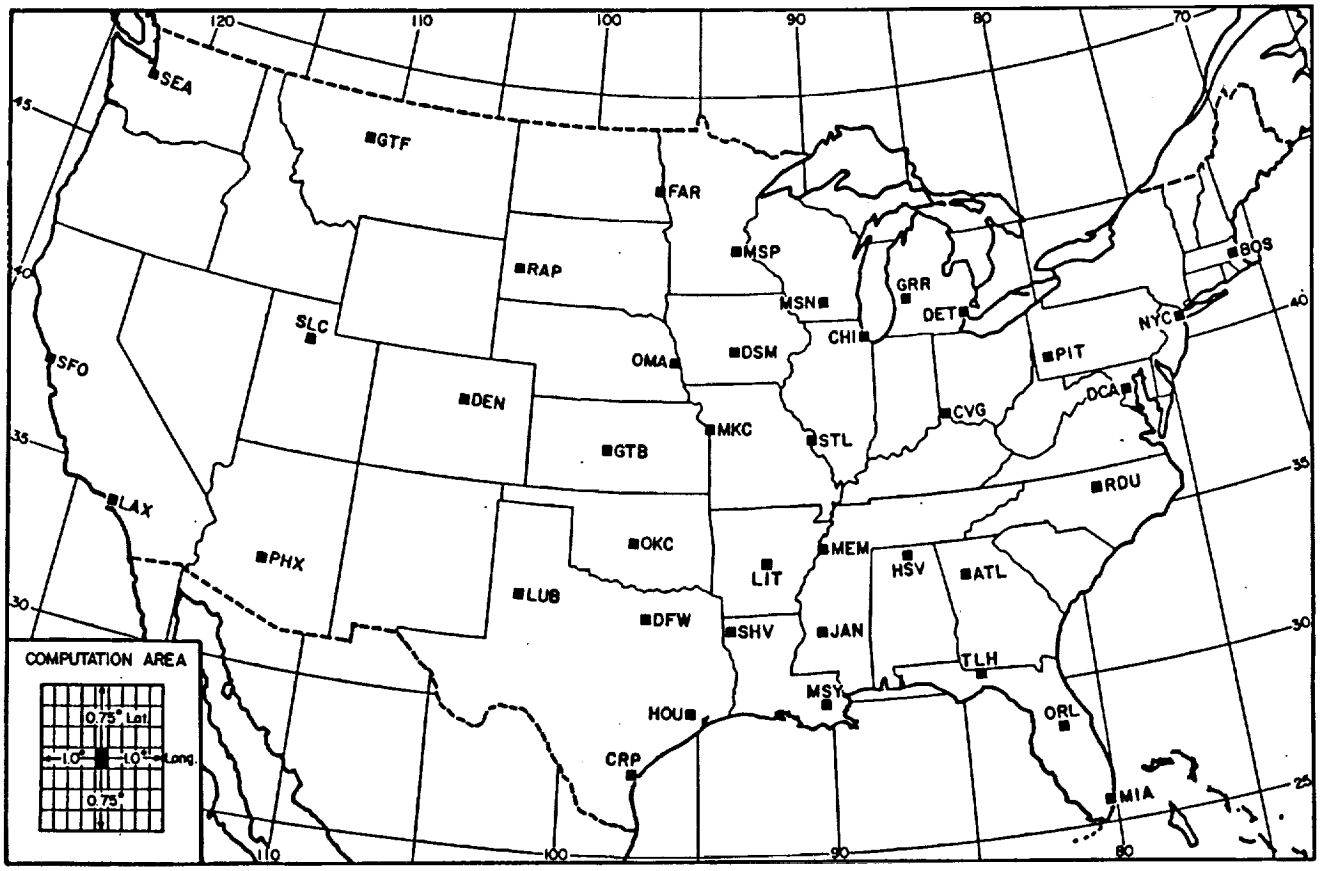
This film shows the track of a research Learjet on satellite pictures, followed by the sequence of views of a growing overshooting top and a collapsing top, beneath which an F2 tornado was in progress. This film documents that the top of the thunderstorm during its tornado-bearing stage is suppressed. The Learjet was manned by Fujita, Forbes, Umenhofer, and Stiegler of the University of Chicago.

J. Summary of ATS III Cloud Movies (250 ft)

This movie was made by combining several scenes filmed between 1967 and 1969. These scenes are:

NOV 18, 1967	Color movie of the planet earth
APR 03, 1968	Fishbone cirrus in jet stream
APR 19, 1968	Tornado situations
APR 23, 1968	Tornado situations
MAY 24, 1968	Jet stream cirrus on moving coordinates
JUN 21, 1968	Hurricane outflow
JUN 22, 1968	Hurricane Candy
FEB 23, 1969	Hook-shaped stratus cloud in satellite movie
APR 23, 1969	Source region of subtropical jet cirrus over the Pacific
AUG 17, 1969	Hurricane Camille in regular and enhanced satellite pictures

Specific Sites of Computing Tornado Statistics



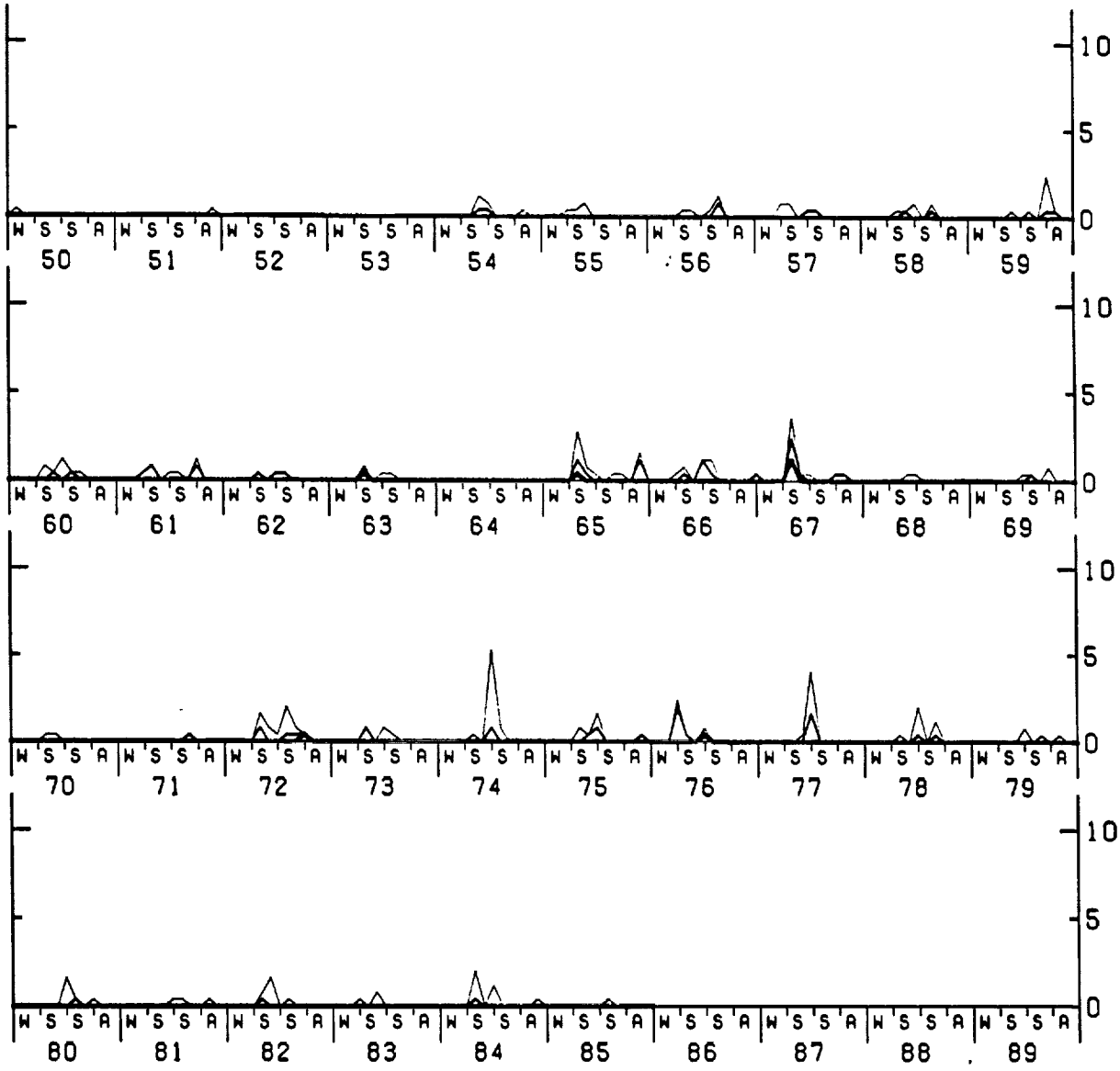
Forty cities selected in computing the long-term variation of tornadoes. Both touchdown counts and path lengths within 1.0° latitude and 0.75° latitude from each city were determined from the University of Chicago Tornado Tape being updated under this NASA Grant, NGR 14-001-008. Included in this fianl report are nine (9) chities, Chicago, IL; Dallas/Ft Worth TX, Denver, CO, Houston, TX, Huntsville, AL; Kansas City, MO, Oklahoma City, OK; Orlando, FL and Washington D.C.

Diagrams for each city are: Tornado counts in four seasons between 1950 and 1988. Tornado in each year from 1916 to 1988 . In order to expand this research into that of "Climatological variation of severe storms, a continuing research proposal was submitted to NASA.

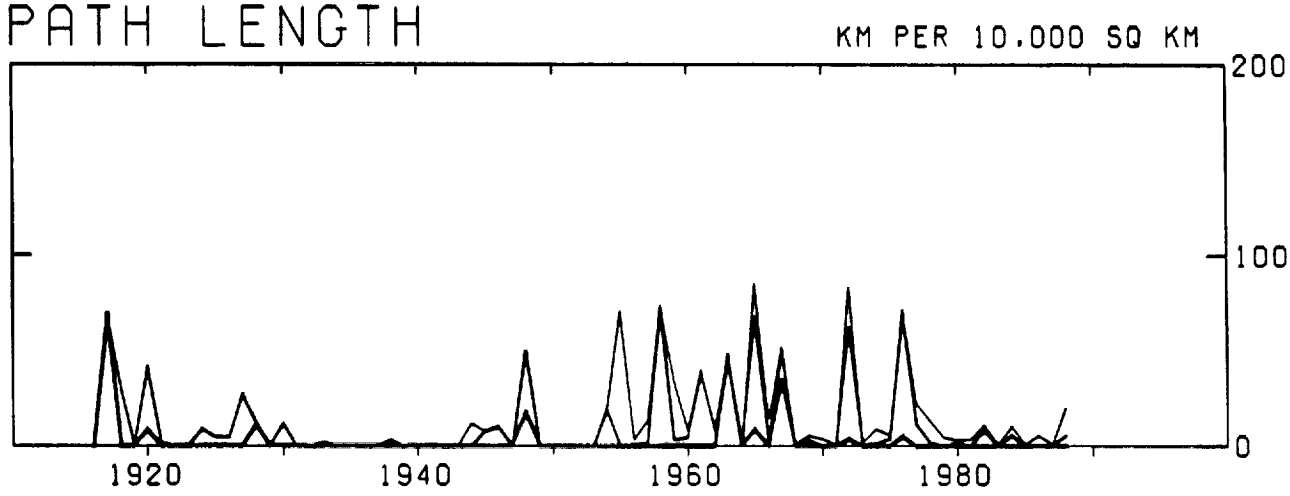
CHICAGO IL

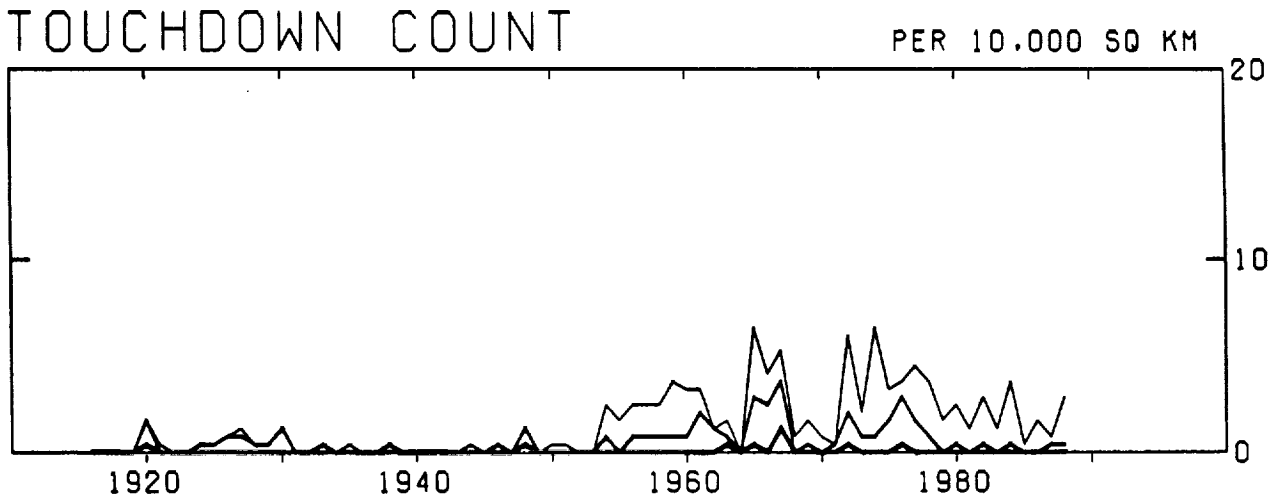
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



CHICAGO IL

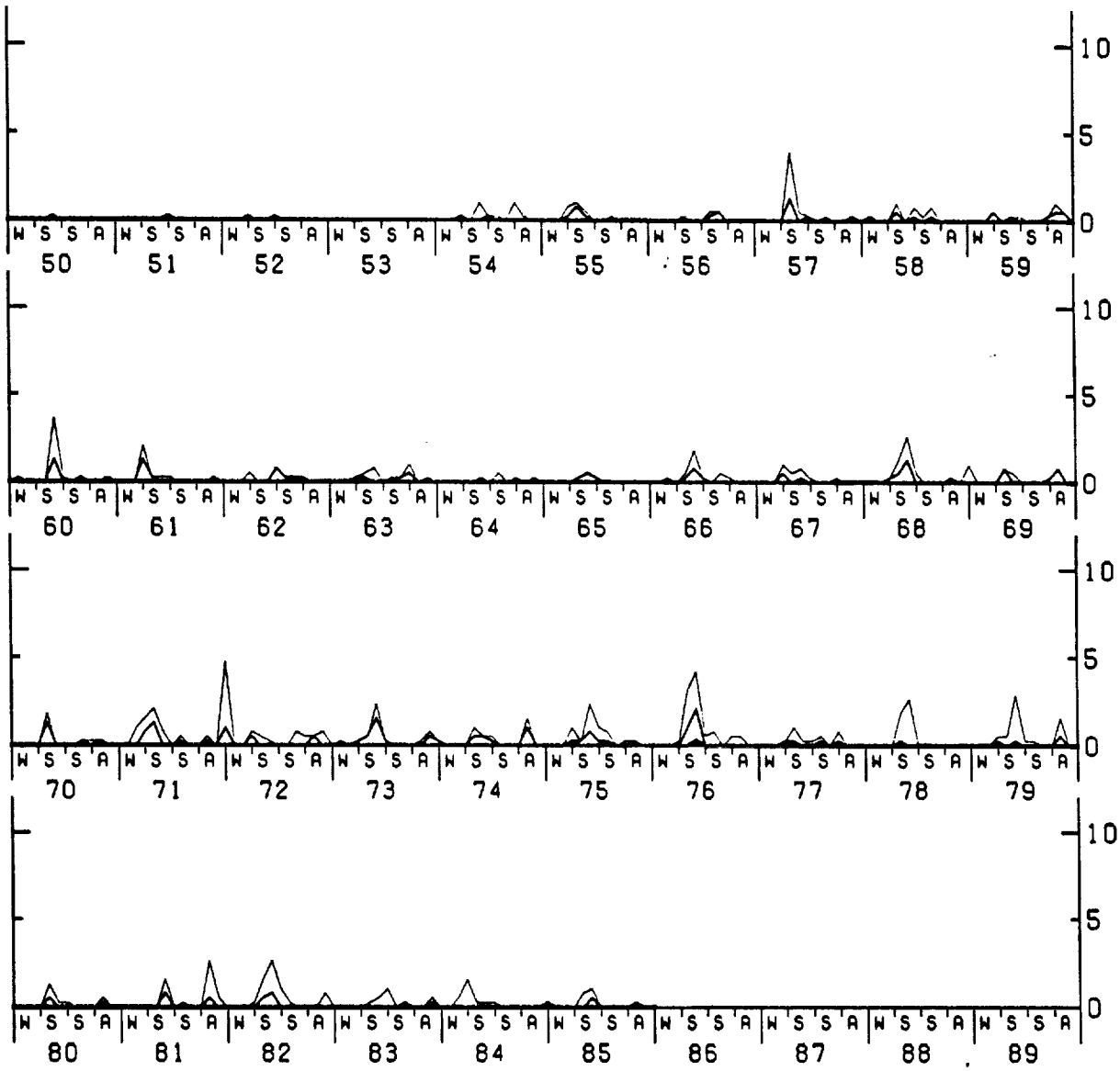

PATH LENGTH
KM PER 10.000 SQ KM
200
100
0
1920
1940
1960
1980


TOUCHDOWN COUNT
PER 10.000 SQ KM
20
10
0
1920
1940
1960
1980

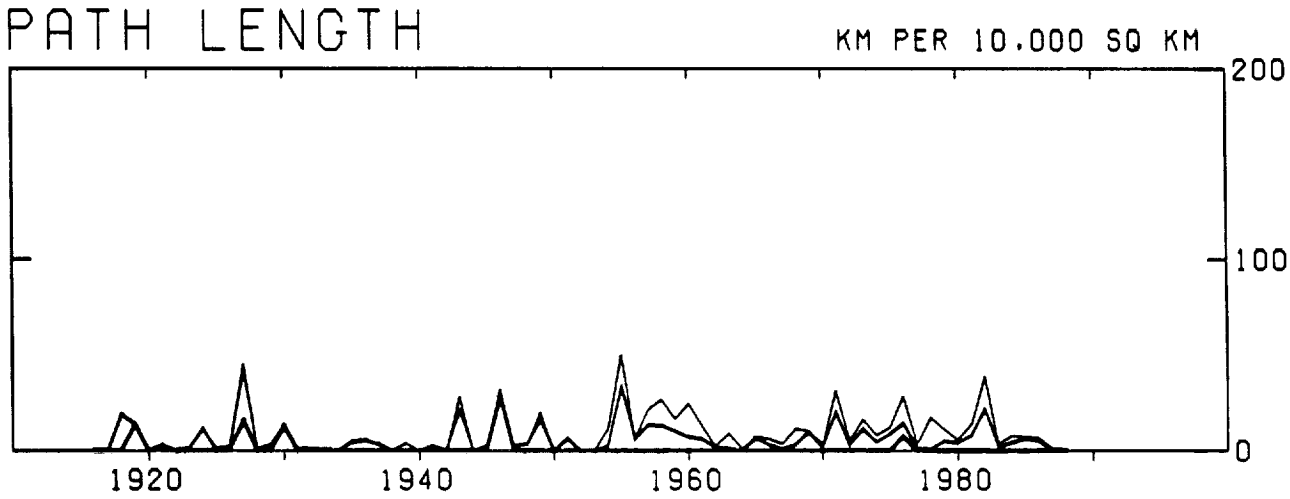
DALLAS/FT WORTH TX

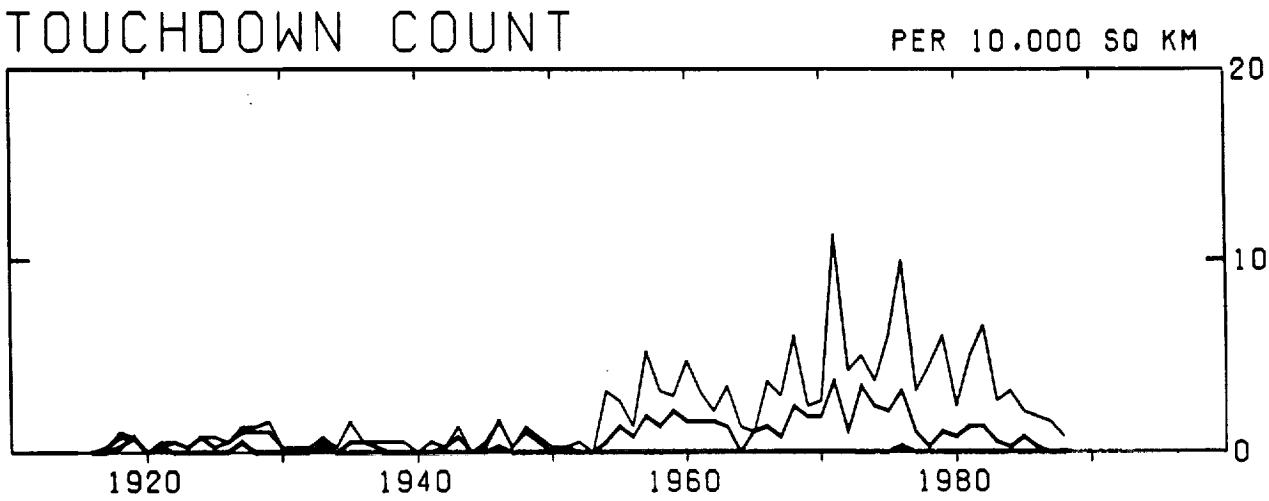
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



DALLAS/FT. WORTH TX

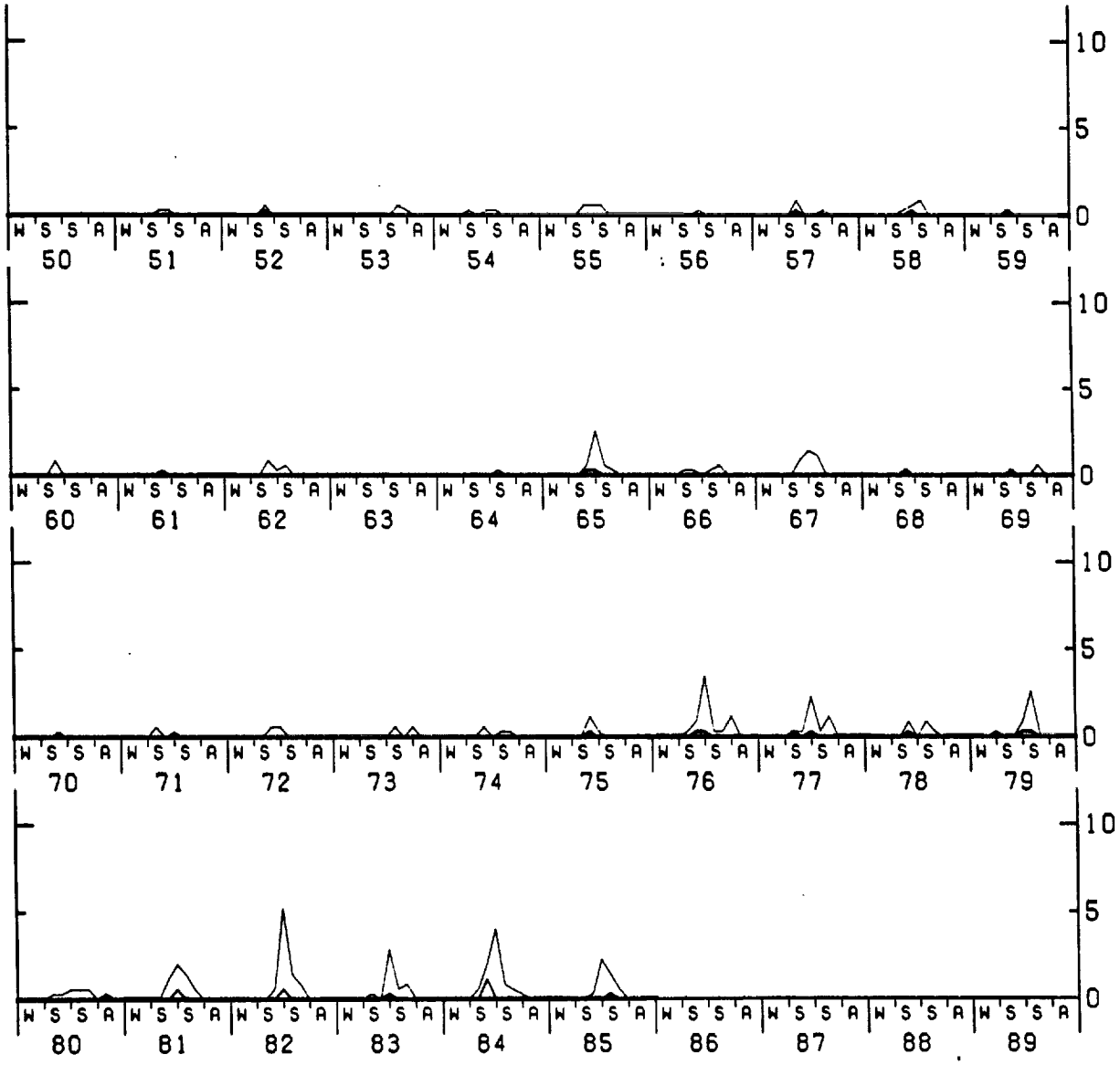




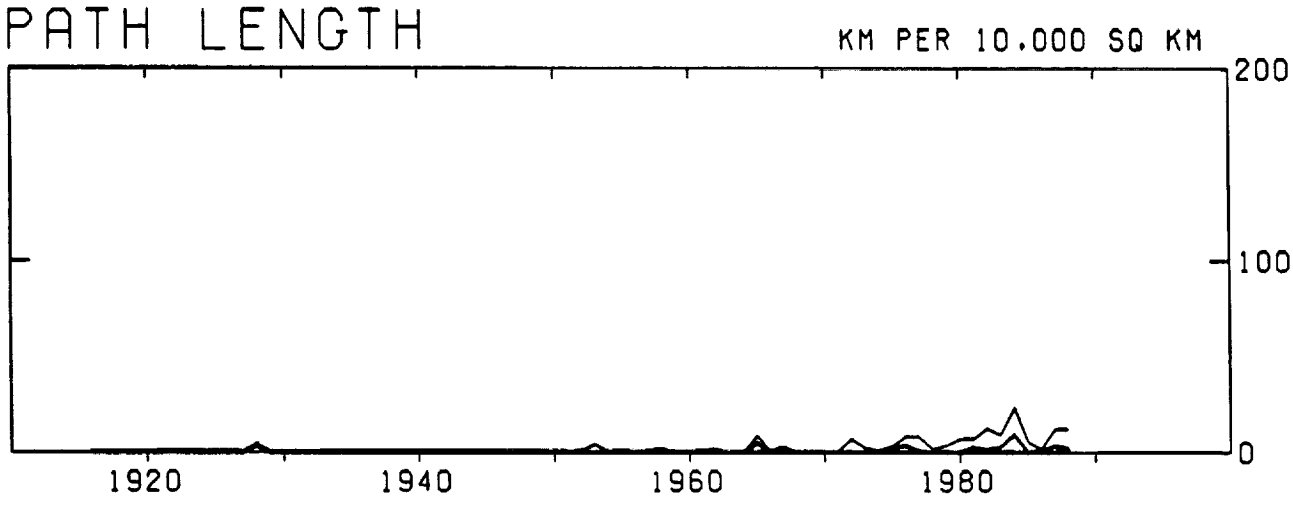
DENVER CO

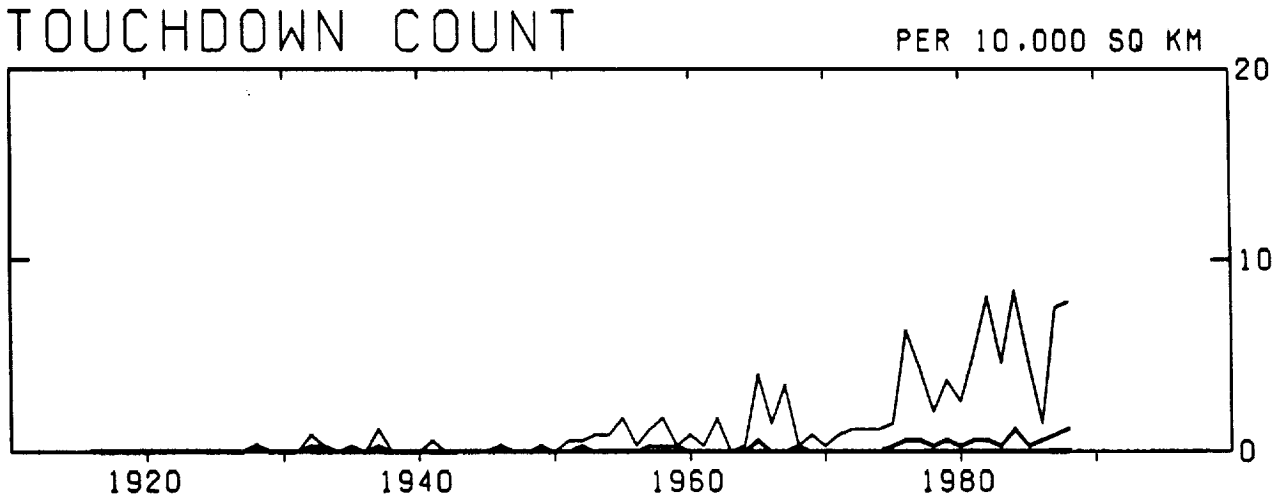
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



DENVER CO

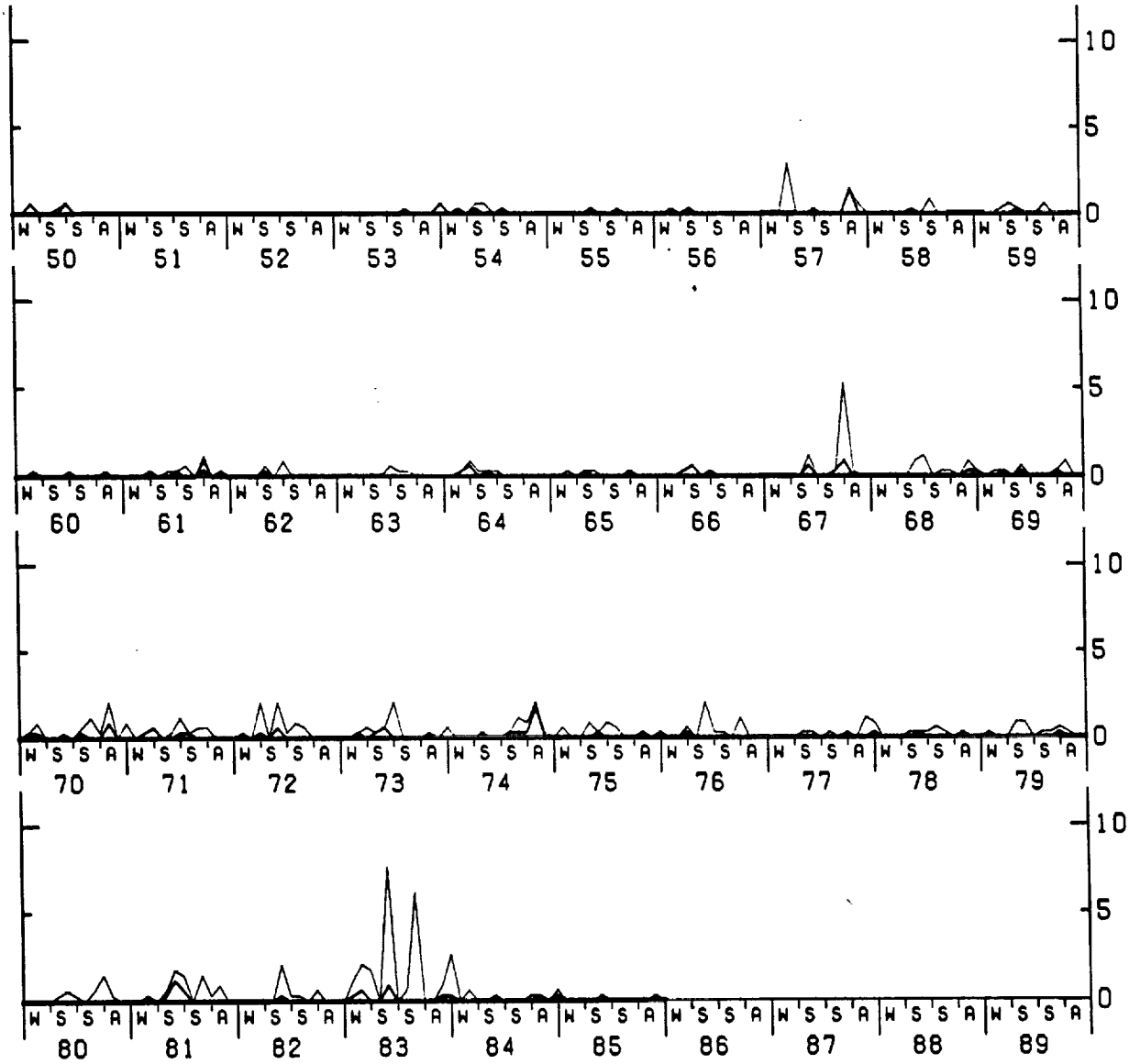

PATH LENGTH
KM PER 10,000 SQ KM
200
100
0
1920
1940
1960
1980


TOUCHDOWN COUNT
PER 10,000 SQ KM
20
10
0
1920
1940
1960
1980

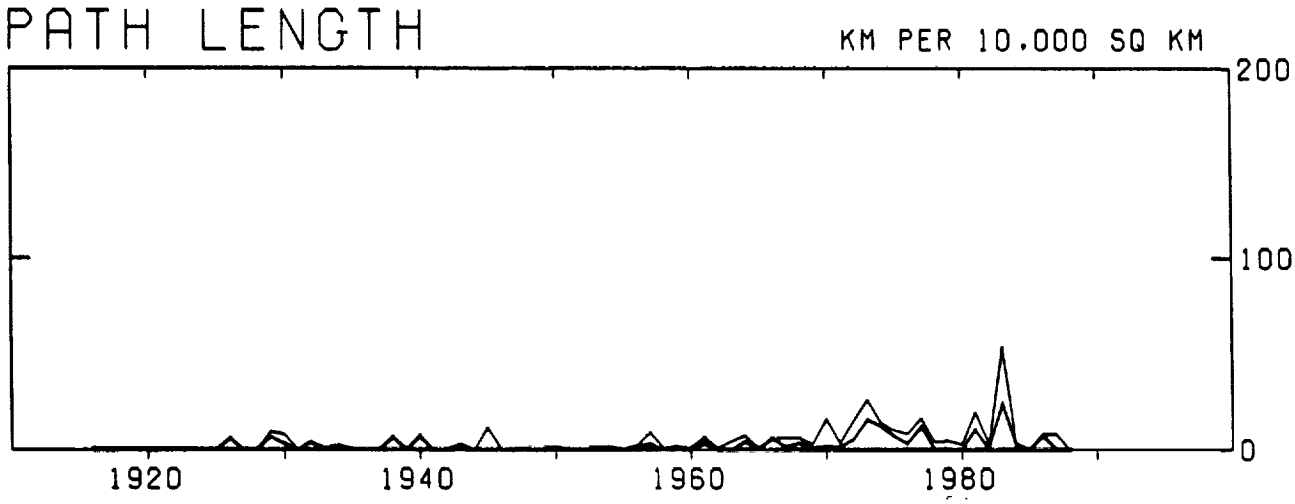
HOUSTON TX

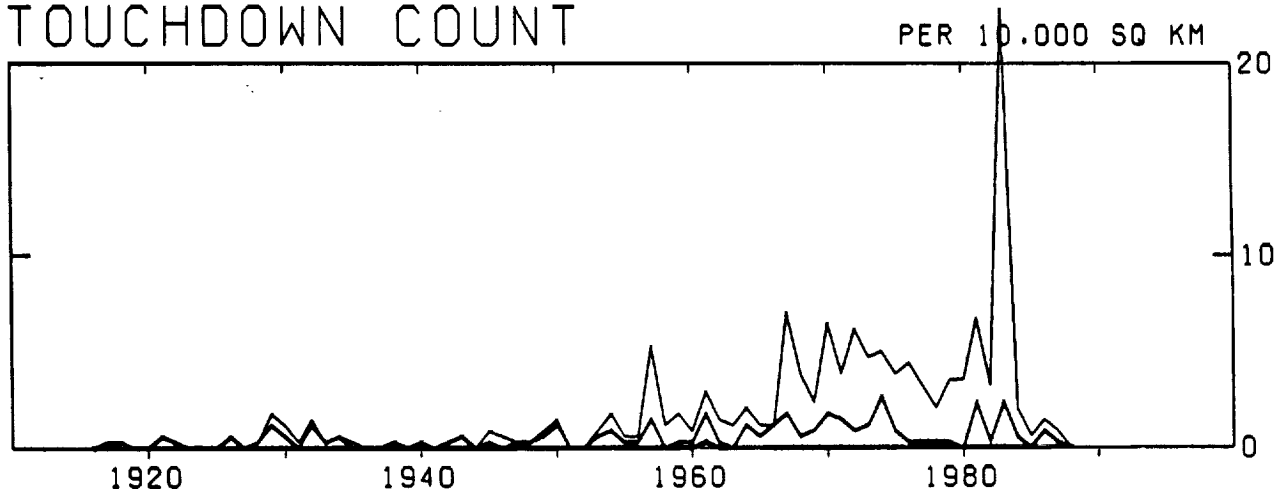
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



HOUSTON TX

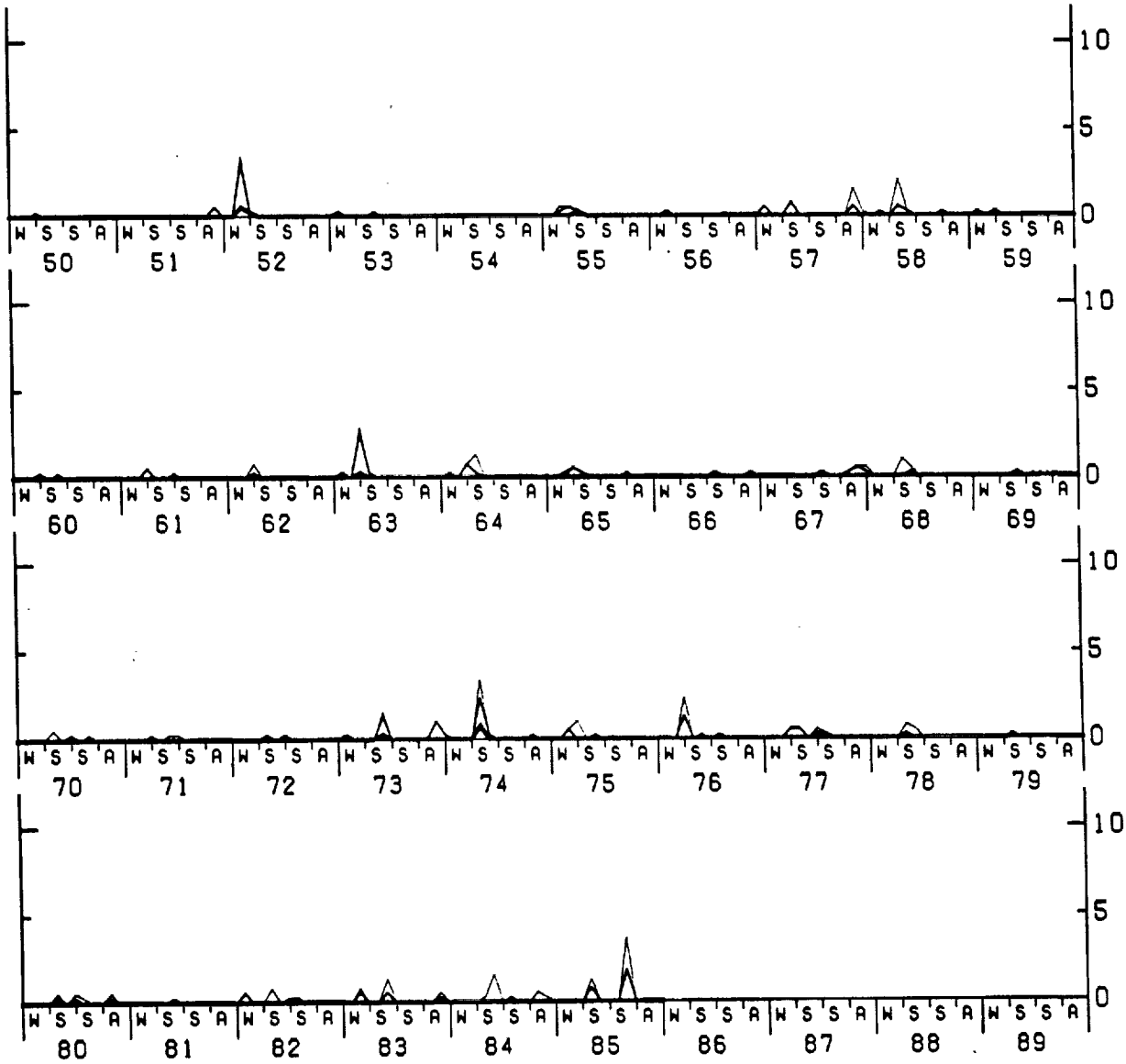

PATH LENGTH
KM PER 10.000 SQ KM
200
100
0
1920
1940
1960
1980


TOUCHDOWN COUNT
PER 10.000 SQ KM
20
10
0
1920
1940
1960
1980

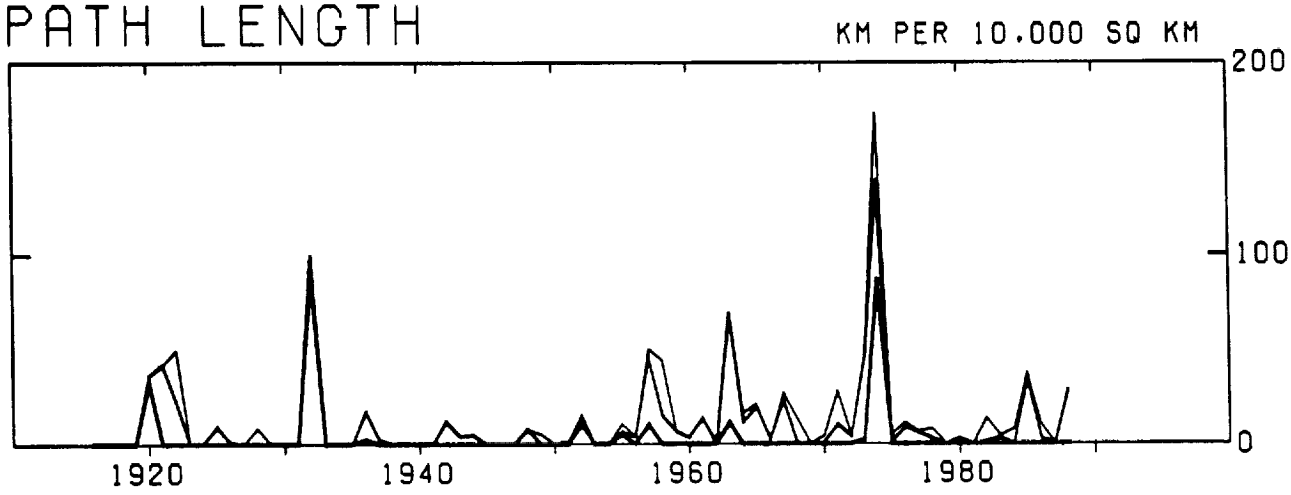
HUNTSVILLE AL

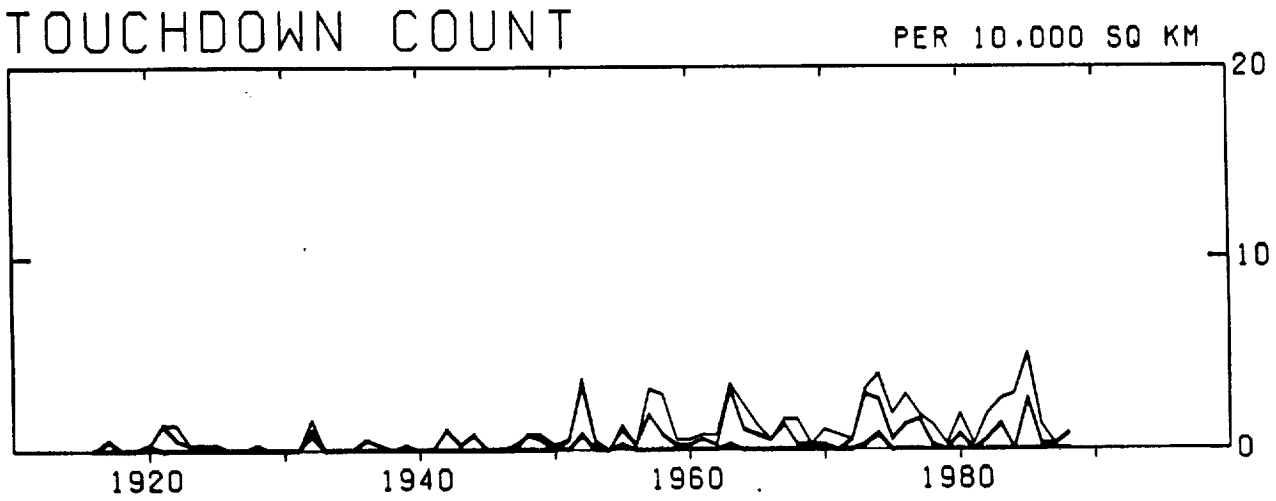
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



HUNSTVILLE AL

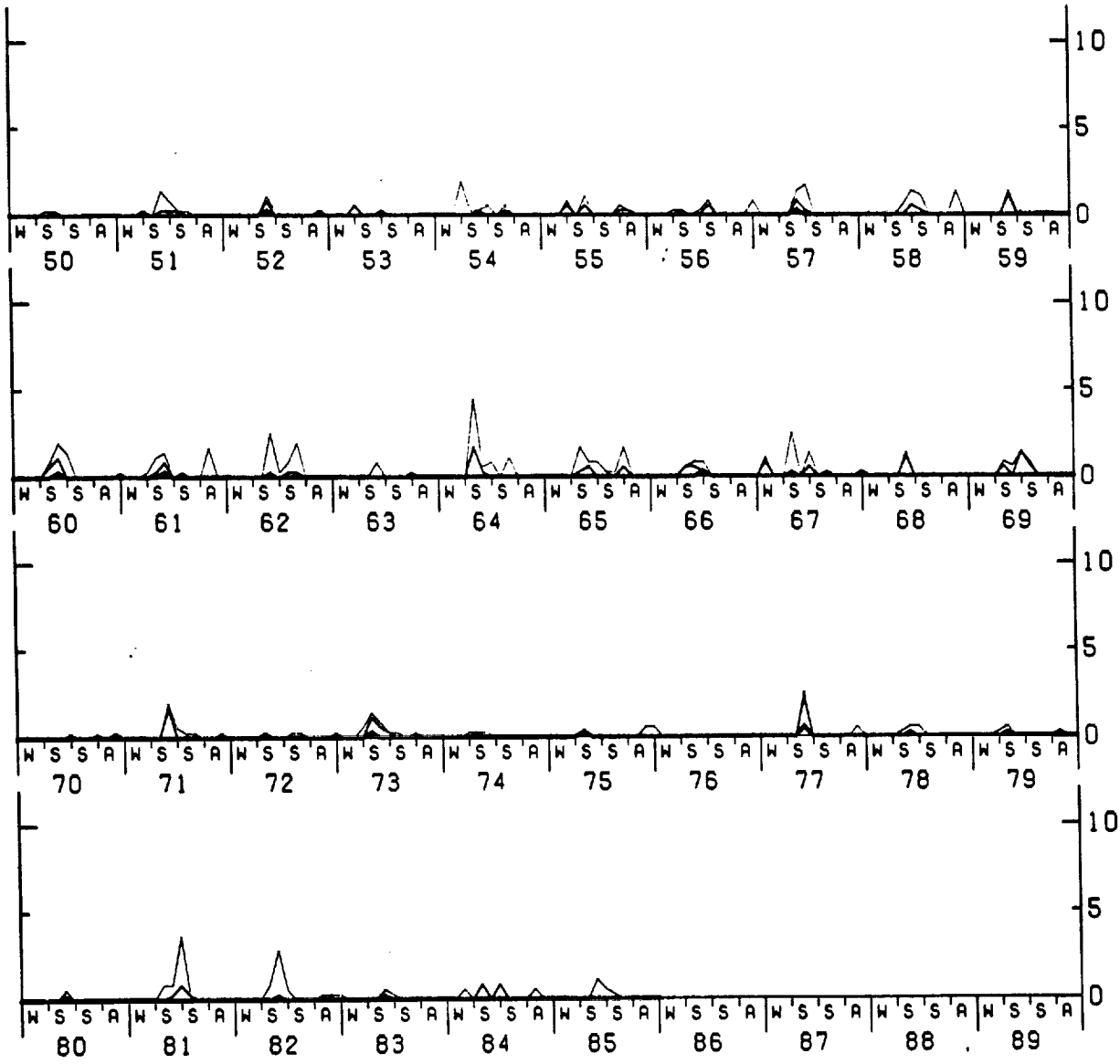




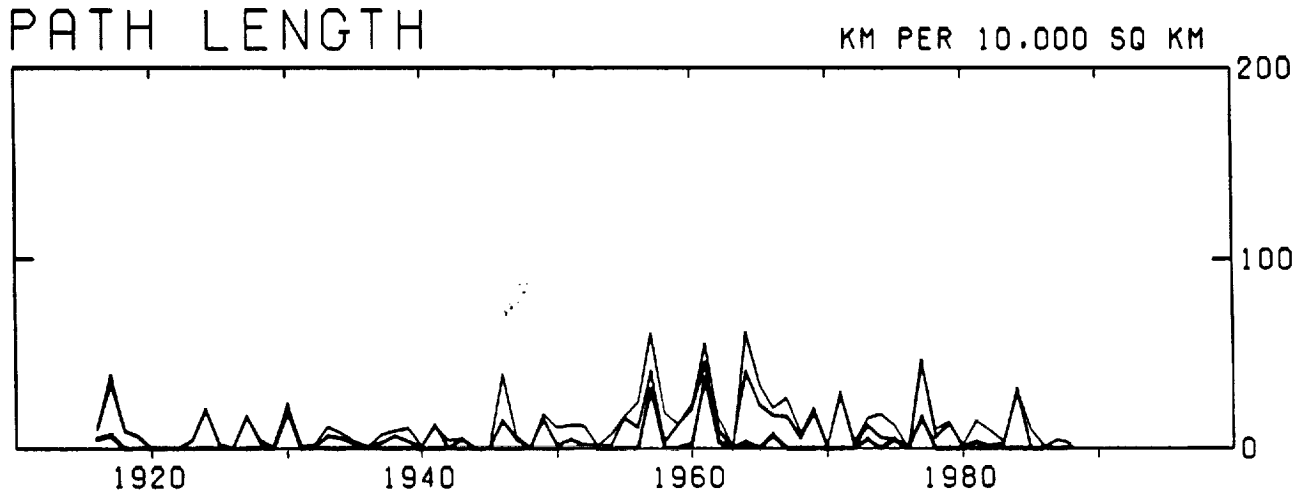
KANSAS CITY

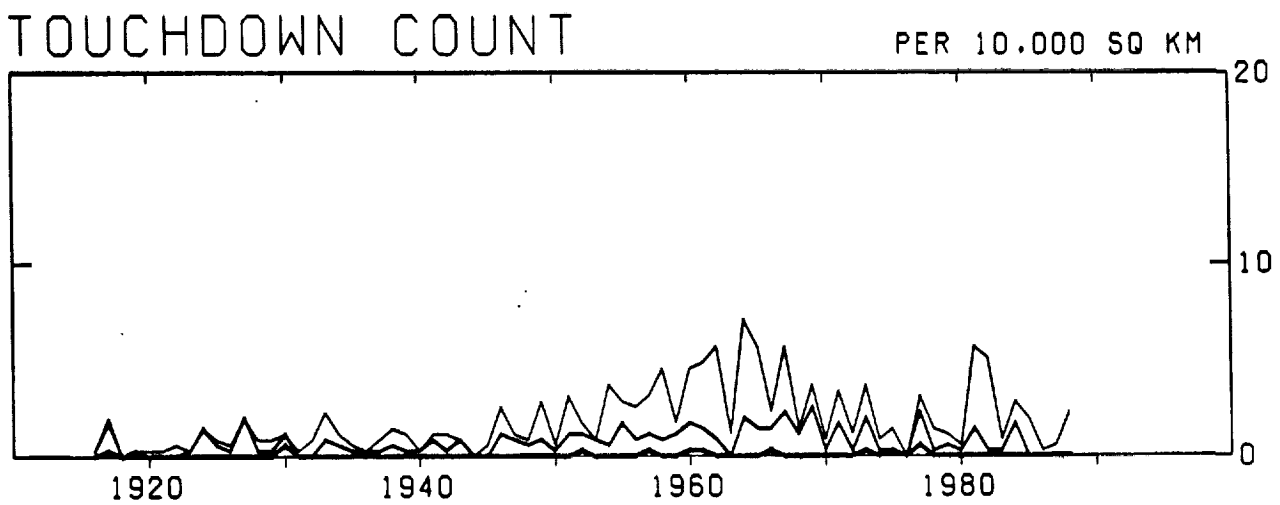
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



KANSAS CITY MO

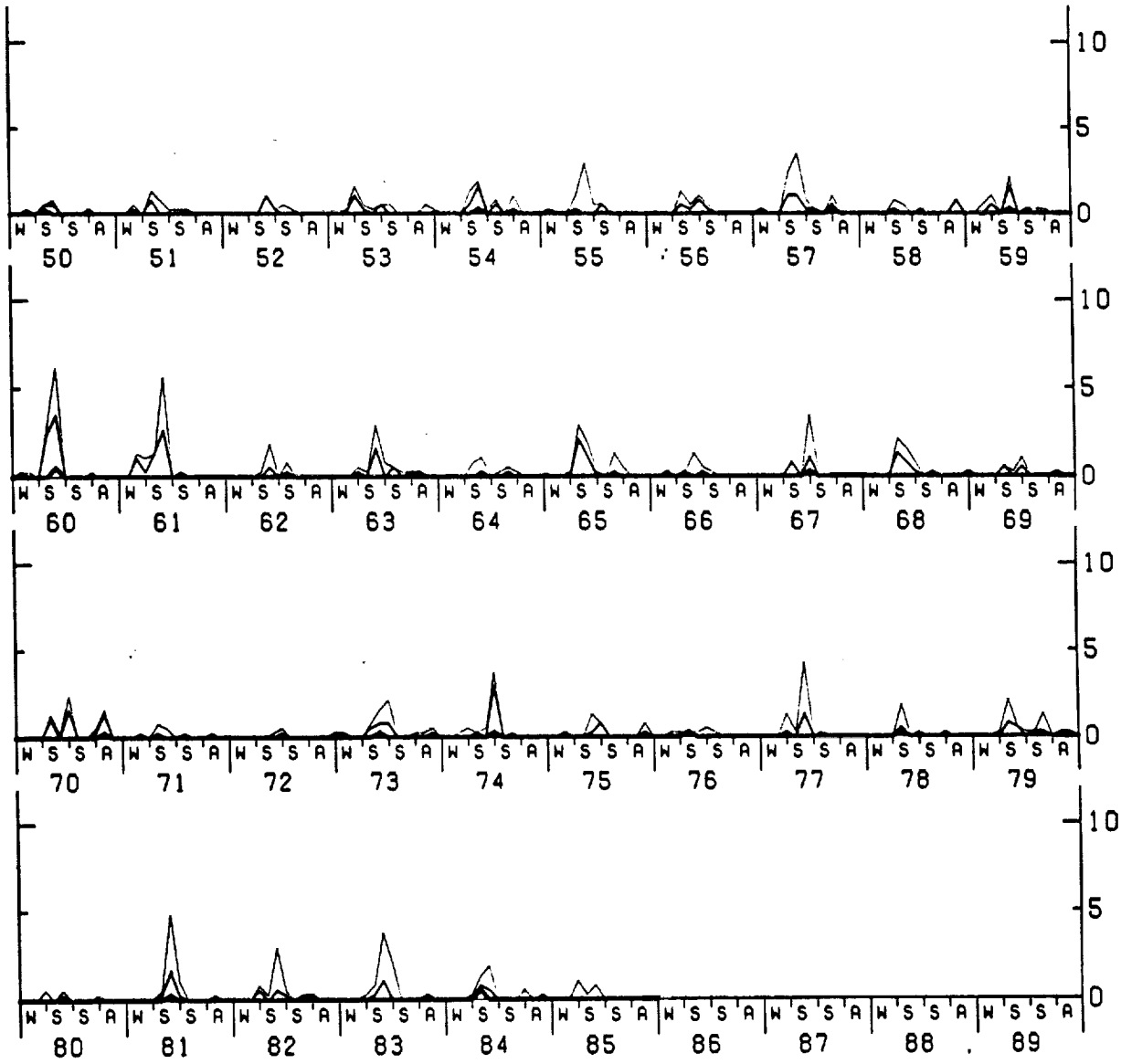




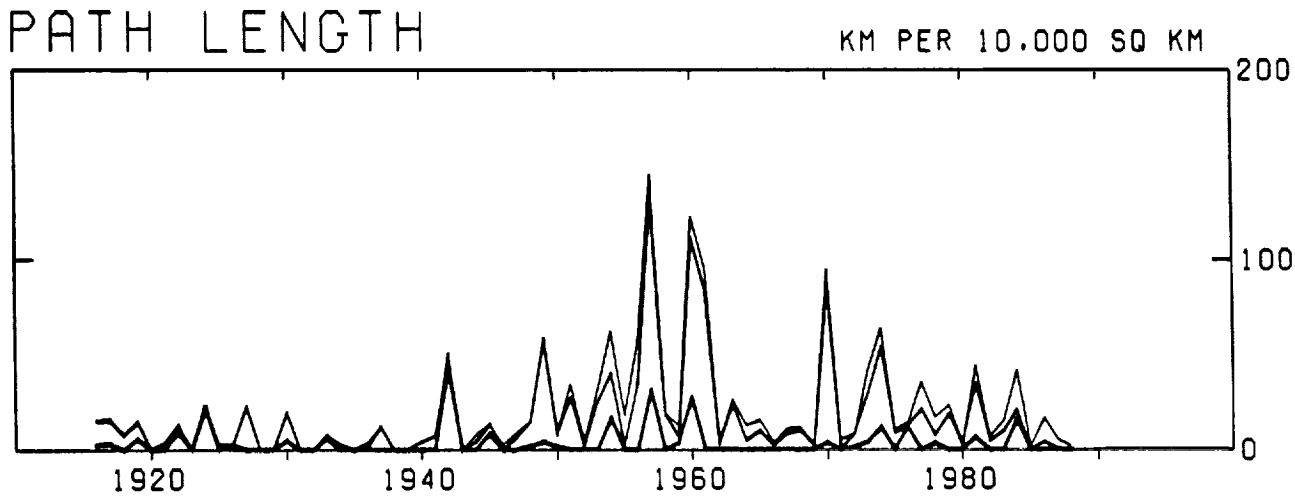
OKLAHOMA CITY OK

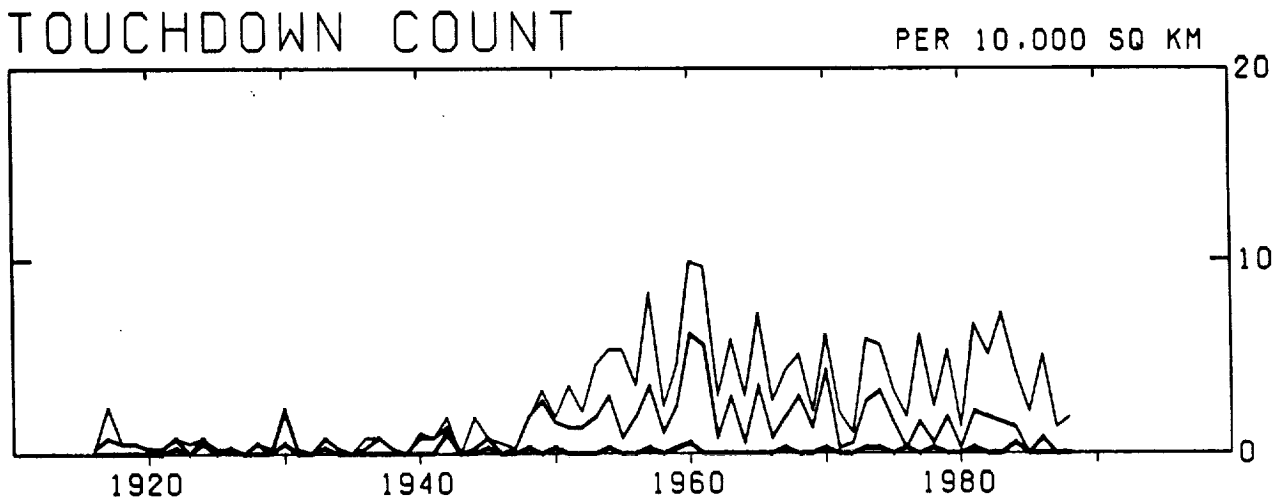
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



OKLAHOMA CITY OK

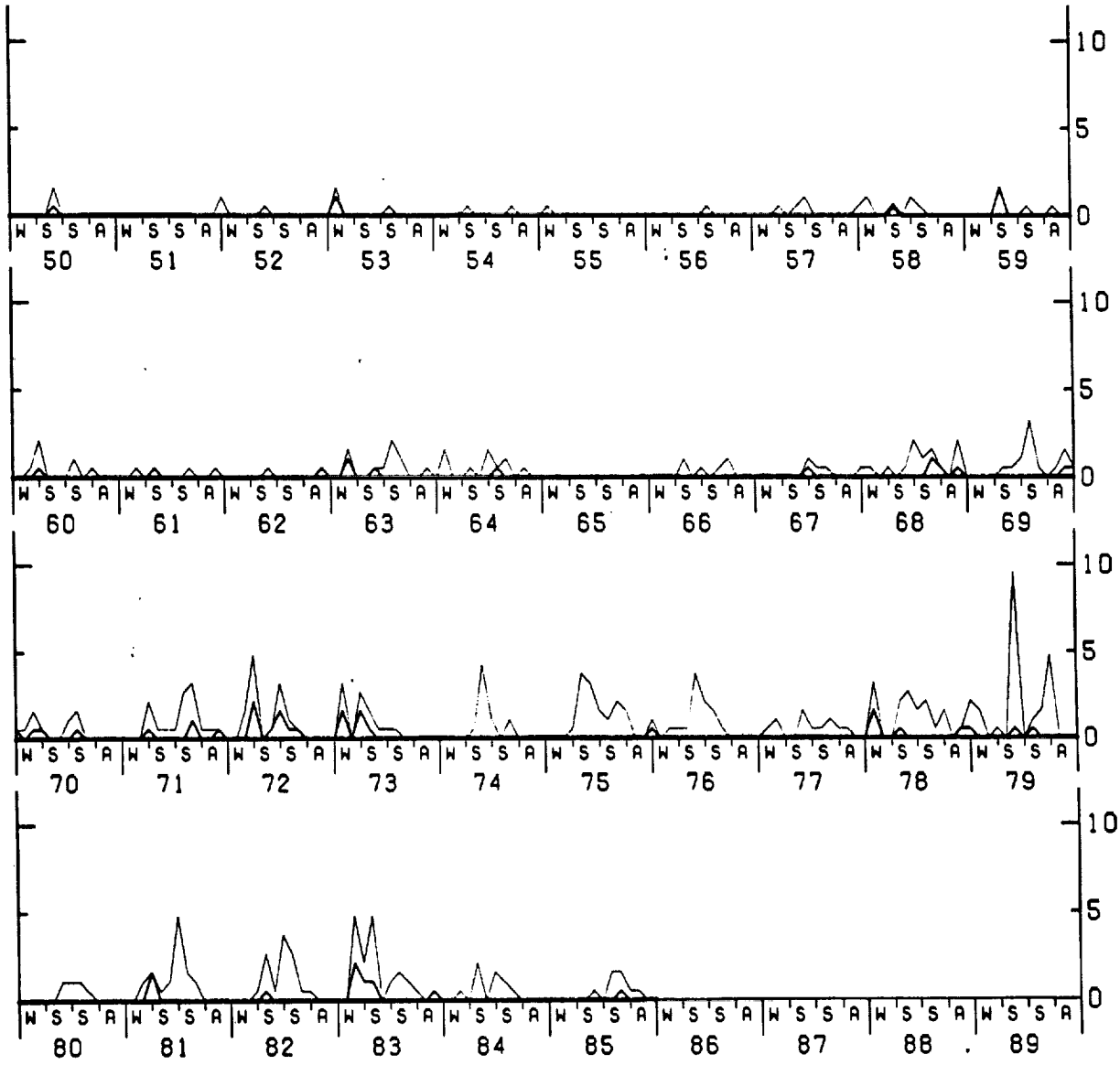




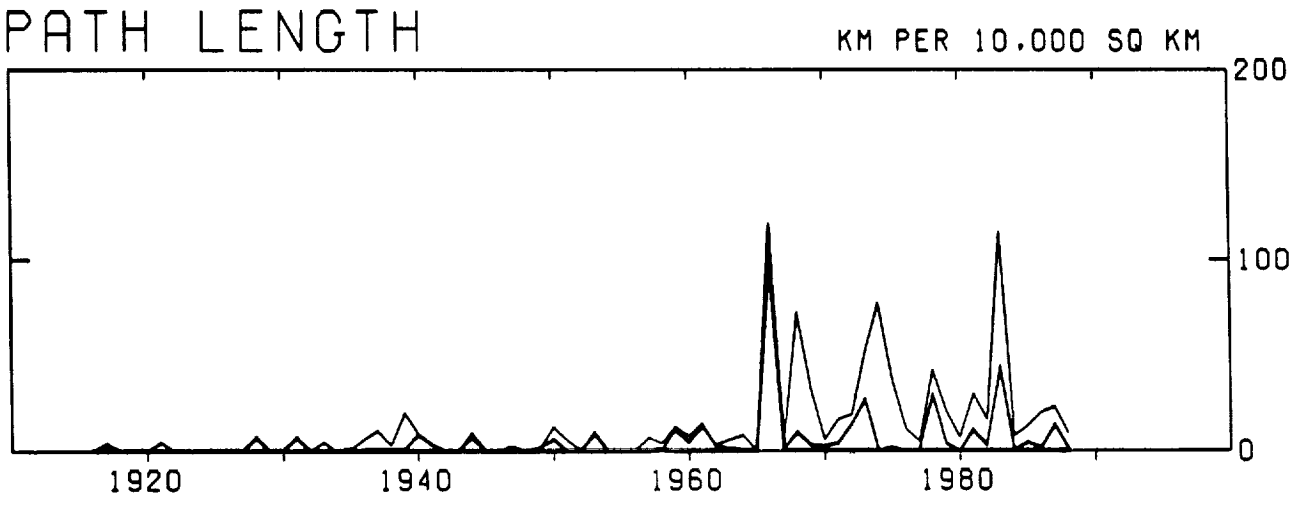
ORLANDO FL

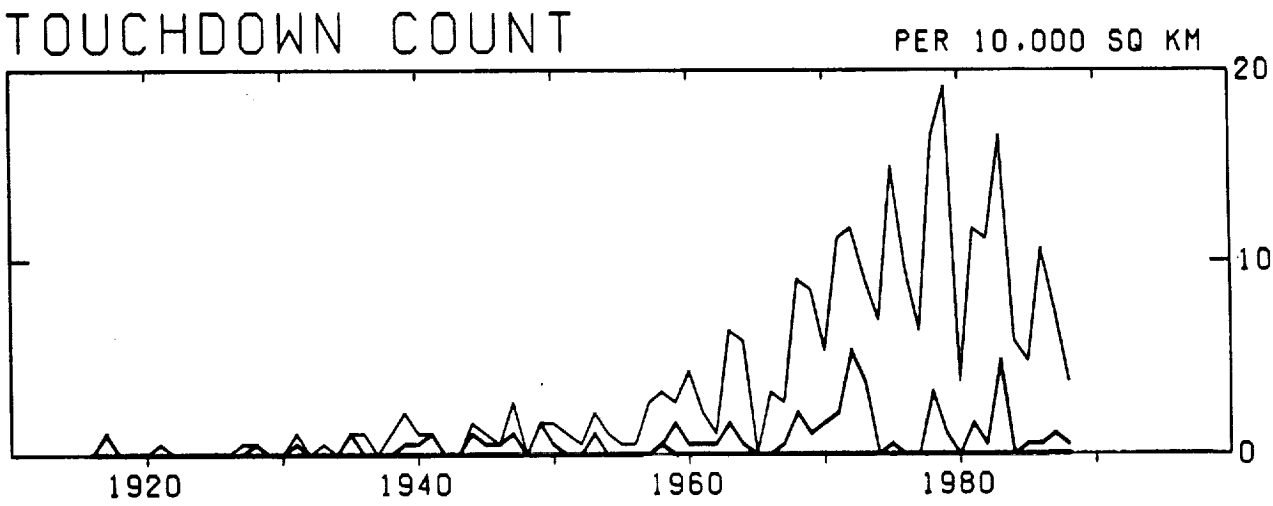
Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



ORLANDO FL

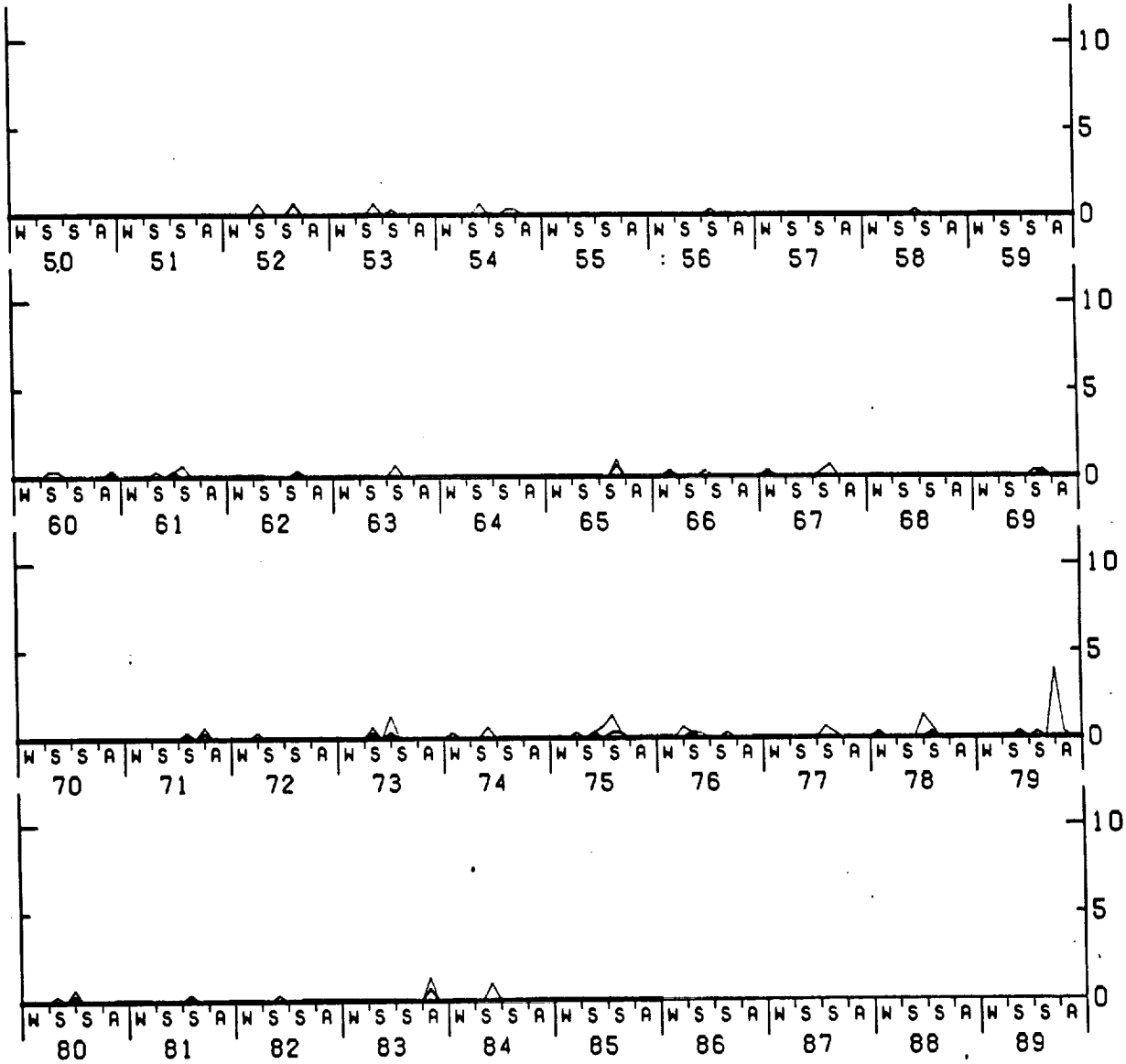

PATH LENGTH
KM PER 10,000 SQ KM
200
100
0
1920
1940
1960
1980


TOUCHDOWN COUNT
PER 10,000 SQ KM
20
10
0
1920
1940
1960
1980

WASHINGTON DC

Touchdown counts of tornadoes between 1950 and 1988 by season in each year. Season identifications are W -- Winter, S -- Spring, S -- Summer, and A -- Autumn. Three thickness lines denote

Thin Line	F0 and F 1 tornadoes
Medium Line	F2 and F 3 tornadoes
Heavy Line	F4 and F 5 tornadoes



WASHINGTON DC